Application of Machine Learning for Beam Profile Monitoring

WP4 Task 4.6 /MS29: ML-based Classification and Evaluation of the Beam Profile Patterns

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on behalf of the IRRAD team
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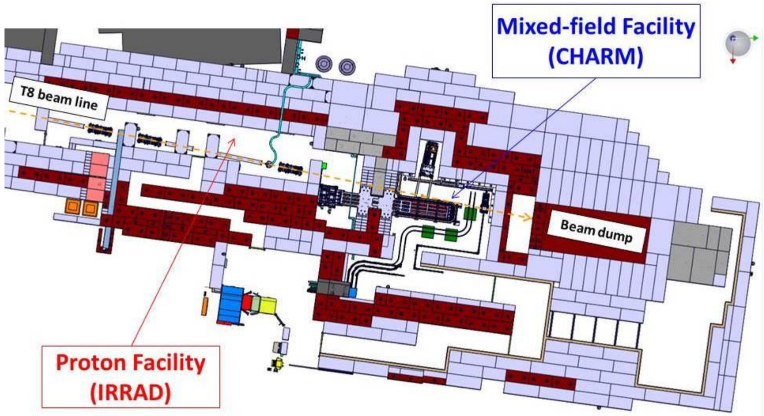
1. Milestone MS29 description

- Work in the framework of **Service Improvements Task** for WP4 Access to Research Infrastructures for Detectors.
- A study of ML applications for Beam Profile Patterns classification and evaluation.
- Strongly related to other Euro-Labs tasks:
  - 4.3.1 CERN IRRAD
  - 4.4.6 Upgrade BPM DAQ

2. Introduction to IRRAD facility



IRRAD Proton Facility

- Located on T8 beamline – a 24 GeV/c proton beam extracted from PS ring.

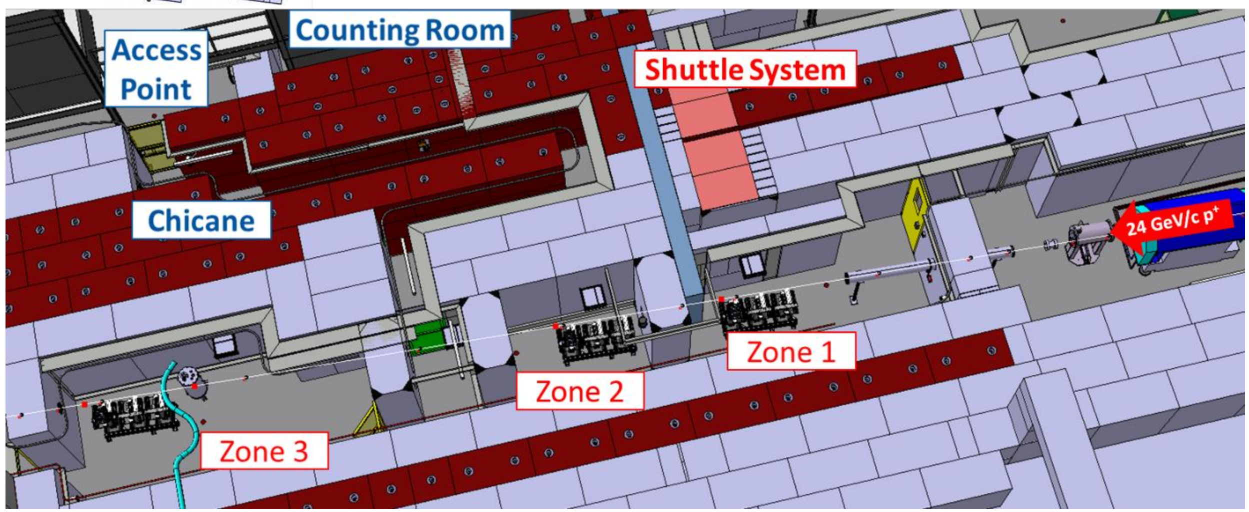
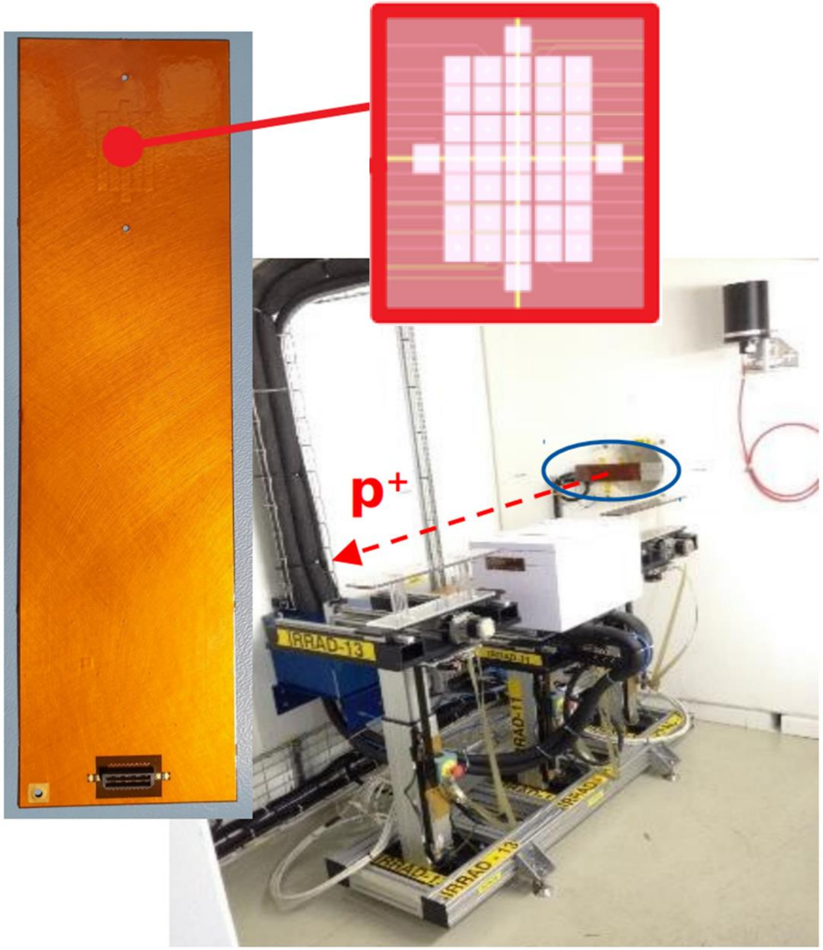


Fig. 1. The location and layout of the IRRAD facility. Divided into three zones and equipped with a shuttle system, it is a place for electronic qualification and radiation hardness assessment.

3. Beam Profile Monitor



- 39 channels
- 1-100 nA range
- 1 kHz sampling rate

- DAQ = 4x39 channels
  ~480 samples/s
  160 MB/day

Fig. 2. Four 39-channel BPMs are used for beam alignment. One DAQ unit supports up to 160 channels with parallel data acquisition of four BPMs. This wealth of data opens the possibility to use Machine Learning-based techniques.

4. Beam Profile Monitoring - data

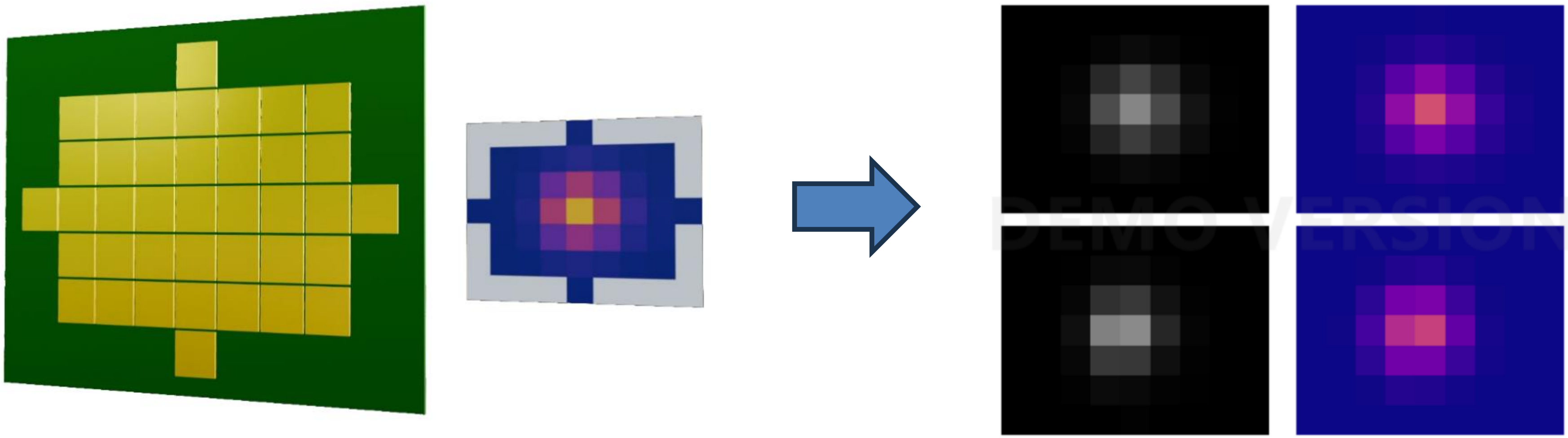


Fig. 3. BPM DAQ (Data Acquisition) electronics is used to monitor the beam profile and store the 39 channels intensities to a database. This existing data was used to create a custom dataset for anomaly detection.

4. Beam Profile Monitoring – current status

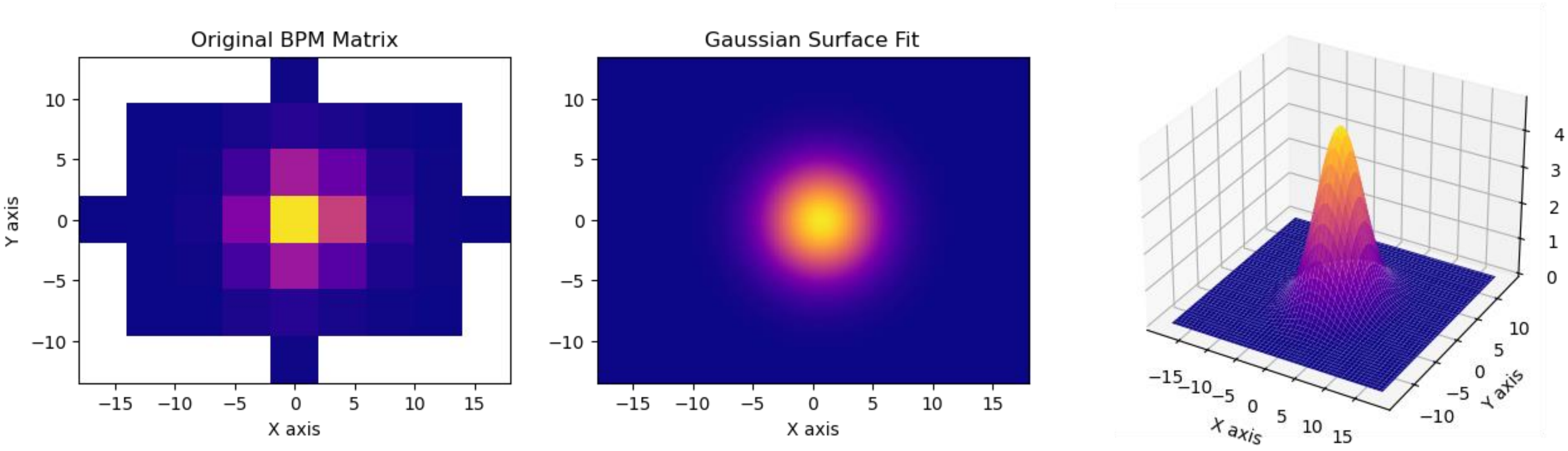
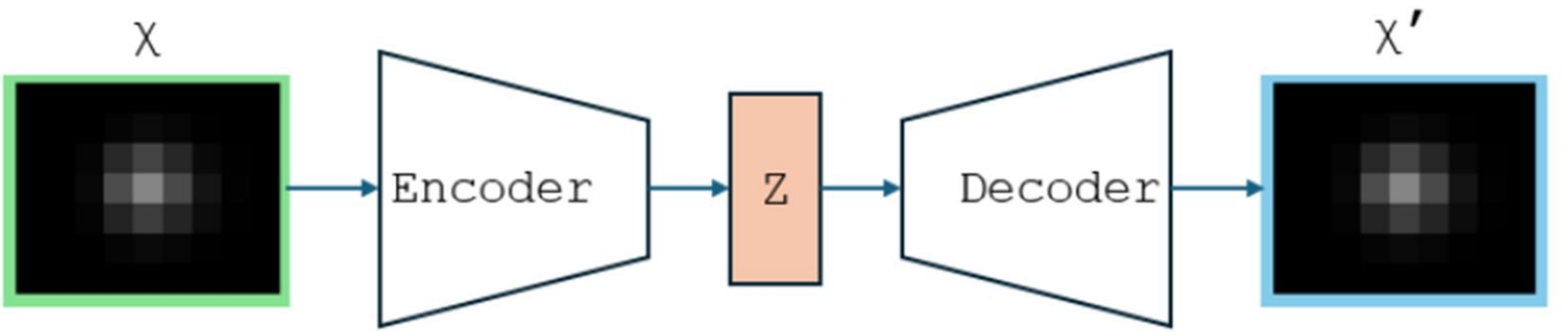


Fig. 4. A first assessment requires the analytical fit of beam profiles to a Gaussian. If the sample meets the required properties, it is labeled as „well-centred beam profile"; otherwise it serves as a counter-example.

4. Autoencoder

- Reconstruction / perfect mapping of known data input χ to output χ'.
- Transition through (smaller) latent Z representation.



4. Autoencoder for Beam Profile Monitoring

Building a Convolutional Autoencoder for BPM:

1. Uses only well-centred beam profiles at learning stage.
2. Works as one-class classifier.
3. Built with Tensorflow and Keras ML libraries.
4. Training process done on Graphics Processing Unit (GPU)
   - with CERN SWAN platform
   - with Nvidia Saturn Cloud grant

4. Beam Profile Monitoring with Autoencoder

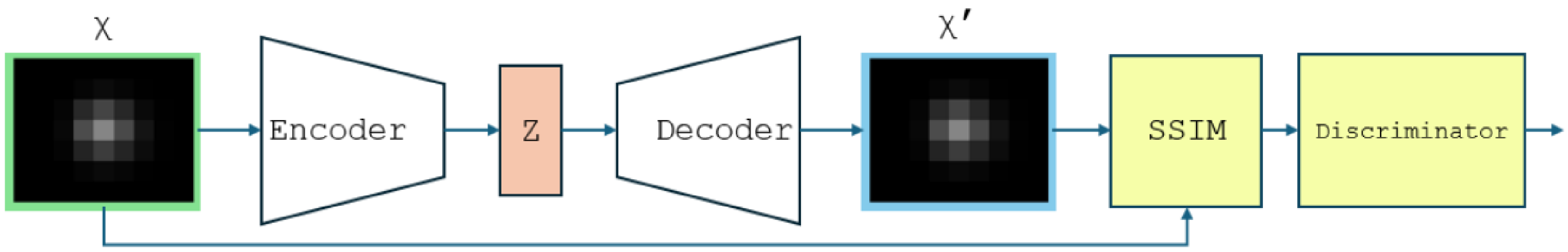


Fig. 6. A Convolutional Autoencoder with SSIM (Structural Similarity Index Measure) metric provides the foundation for real-time anomaly detection (off-centred beams).

5. Deliverables and results

- First dataset of beam profiles, with their annotations
- Data pipeline for measurements pre-processing
- 16x speed improvement for real-time operation
  - Analytical method: 79 samples/s
  - ML classification: 2,951 samples/s

6. Perspectives

- Data correlation with Multi-Wire Proportional Chamber.
- Full analysis on autoencoder operations, including:
  - Autotuning for BPM tasks
  - Comparison of various autoencoder architectures
- Definition of ML models to assess beam spatio-temporal characteristics.

Links and available resources

1. „ML-Based Classification and Evaluation of the Bean Profile Patterns" – Euro-Labs report

2. PS IRRAD Irradiation Facility (dr F. Ravotti) https://ps-irrad.web.cern.ch/ps-irrad/

Acknowledgements

www.web.infn.it/EURO-LABS

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